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OF SONIC-BOOM SIGNATURES

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ABSTRACT

Special considerations are involved in the selection of instrumentation for meaningful sonic-boom measurements. Because of the nature of the sonic-boom pressure signature, the requirements include usable frequency response from nearly dc to several thousand cycles in the pressure range 0.1 to 10 pounds per square foot. A specially developed NASA instrument system is described along with techniques of measurement. The problems of vibration isolation, wind screening, long cable lengths, and field calibrations will be discussed, and some sample data will be presented.

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INTRODUCTION

Results of studies concerning the responses of structures and people to sonic-boom exposures have suggested that the signature shape is important, and hence considerable effort has been expended in the past to develop instrumentation systems suitable to faithfully reproduce the entire sonic-boom pressure time history. Some of the features of the sonic-boom pressure signature that are believed to be important are illustrated in the first figure. Shown as an example in the figure is an N-shaped wave such as would be experienced due to a sonic boom at a fixed measurement location. Such quantities as the peak overpressure Δp which varies generally from 1 to 10 lb/ft^2, the wavelength T which may vary from 0.05 to 0.30 seconds, and the associated impulse functions and rise times τ are defined in the figure for a sample measured signature.

The purpose of this paper is to document the description of a sonic-boom measurement system now in use and which is adequate for the measurement of the various wave forms encountered in practice. Included is a general description of the equipment, some of its special operating features, and a discussion of the procedures for using this equipment in field measurement experiments.

SPECTRAL CONTENT OF SONIC-BOOM WAVES

In order to determine the required characteristics of sonic-boom measuring systems, it is necessary to know the physical properties of the waves to be measured, and in particular their frequency spectra.

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The spectral content of an idealized N-wave having a period of 0.10 second is presented in figure 2. Relative amplitude on the vertical scale is shown as a function of frequency on the horizontal scale. The curve represents the envelope of the spectrum of the wave based on Fourier integral techniques. (See ref. 1.) It can be seen that the spectrum peaks in the vicinity of 10 cycles per second and falls off quite rapidly both below and above this frequency, the 40 dB down points being at about 0.03 cps and 1,000 cps, respectively. It is significant to note that the spectrum extends from the subaudible range into the speech frequency range. Conventional microphone systems are generally adequate for defining the high-frequency range requirements, but some special considerations must be given to the problem of measuring the low frequencies which are generally lower than conventional microphone equipment is designed for.

An example of the effects of system frequency range deficiency, at both high and low frequencies, is illustrated in figure 3. The top trace represents an N-wave sonic-boom disturbance of the type to be reproduced. The middle trace represents the type of result that would be obtained with a system having adequate high-frequency response but which is deficient in low-frequency response. This is typical of actual data records obtained with condenser microphone systems having a frequency response generally flat from about 10 cps to 10,000 cps. In this case, it is possible to define the peak pressures but the details of the wave associated with its slowly varying portion are lost. The trace at the bottom of the figure, on the other hand, is representative of measurements made with a system having low-frequency response to dc but being deficient in its high-frequency response. Data records such as these have been obtained with microbarograph equipment having a generally flat frequency response from zero to about 30 cps. It can be seen that the gross features of the wave are preserved, but the small details associated with the rapidly rising portion of the wave and particularly the peak-pressure value are distorted. It is obvious that in order to obtain satisfactory N-wave-type signature measurements, there is a requirement for a system having the best features of the microbarograph on the one hand and the microphone on the other; that is, a usable frequency range from near zero and extending through the audible range.

At the time of the first sonic-boom measurements, there was no commercially available microphone system having the desired frequency characteristics. As a result, it was necessary to make modifications to an existing system, in particular the transducer, in order to obtain the required characteristics. The frequency-response characteristics of the transducer before and after modification are illustrated in figure 4. It can be seen that before modification the transducer, which was a standard commercially available condenser microphone as indicated schematically in the sketch, had a frequency roll-off below about 10 cps. It was desirable to extend the flat part of the frequency response to lower frequencies, and this was accomplished by changing the configuration of the chamber vent (see schematic diagram) behind the diaphragm. Basically the venting rate was diminished in order to obtain the intermediate dashed curve of the figure. It would, of course, be possible to eliminate the vent completely and obtain essentially dc. The modified vent configuration was used, however, as a satisfactory compromise since it allows adequate provision for temperature and atmospheric pressure changes during field operations.

In order to take full advantage of the beneficial low-frequency response of the microphone illustrated in figure 4, it is necessary to make use of a system of the type shown in the block diagram of figure 5 rather than a conventional condenser microphone system. In this system the condenser microphone and the coil adapter unit are used together to form a tuned circuit similar to an FM carrier circuit. By making use of the proper signal-conditioning equipment, various means of data recording can be made use of as indicated schematically on the right-hand side of the figure.

Systems of the type described in figure 5 have been used essentially for field measurements. These systems are noted to have several special features which are particularly desirable in field operations. For instance, battery operation makes them self-contained for remote locations; they have the capability of driving long cables; and cable lengths of up to 2 miles have actually been used with this system. Other features of note are the provision for system sensitivity checks in the field by means of static-pressure devices, impulsively or statically, and with the use of data-write equipment the availability to produce quick-look records.

The transient response of the main elements of the system including microphone, tuning unit, and recording galvonometer are illustrated in figure 6. In order to evaluate the system, a square wave signal having a 50-microsecond rise time was applied to the microphone diaphragm by means of an electrostatic transducer. It can be seen that the system follows the input signal faithfully with the exception of a small overshoot associated with the rapidly varying portions of the wave. This overshoot which is of the order of 12 percent of the peak value is believed to represent the maximum distortion by this system of the type of transient signals normally measured in sonic-boom experience. This conclusion is based on the fact that distortion of the type illustrated in figure 6 is a function of the rise time, and rise times of sonic-boom waves measured in field experiments are generally an order of magnitude longer than those of the calibration signals of figure 6.

MEASUREMENT TECHNIQUES

In addition to the many detailed considerations in the design and operation of a measurement system there are also some important considerations in its use. Some of these can be described with the aid of figure 7. (See ref. 2.) As suggested by the sketch at the top, measurements can be made at various levels above the ground surface. Depending on the elevation of the measurements for given flight conditions and reflecting surface conditions, different signature results will be obtained as illustrated by the traces at the bottom of the figure. The top trace represents a condition such that the incident and reflected waves are completely separated and thus, a free-air measurement is obtained. The bottom trace represents ground-surface-measurement conditions where the incident and reflected waves are in phase and the peak overpressures are about twice the free-air values. The middle trace represents an ear-level condition where the incident and reflected waves are superposed but are not fully in phase. For reasons of convenience, the ground-surface measurement has become conventional as a reference.

In order to perform such a ground-surface measurement with the system of figure 5 some special considerations which are illustrated in figure 8 are believed to be important. Shown at the top of the figure is a photograph of a ground-measurement installation showing the reflecting board and wind screen. The reflecting board forms a rigid plane surface having dimensions about 100 times the microphone size to provide nearly perfect reflection in the area of the transducer and is securely mounted flush with the ground. At the bottom of the figure is a section view showing some microphone installation details. The microphone is installed such that its diaphragm is parallel with the reflecting board and is shock mounted to minimize the detrimental effects of ground vibration during the passage of the shock wave.

CONCLUDING REMARKS

Some of the special considerations involved in selecting instrumentation for sonic-boom measurements have been discussed. It was noted that a useful frequency range from a fraction of a cycle on the low end, and extending upward to include the speech range on the high end is required. A specially developed measuring system has been described along with some measurement and calibration procedures. Such related topics as vibration isolation, the use of long cables, and temperature and pressure gradient compensation have also been mentioned briefly.

REFERENCES

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2. Hubbard, H. H.; Maglieri, D. J.; Huckel, V.; and Hilton, D. A.: Ground Measurements of Sonic-Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet and at Mach Numbers to 2.0. NASA TN D-2021, 1963.

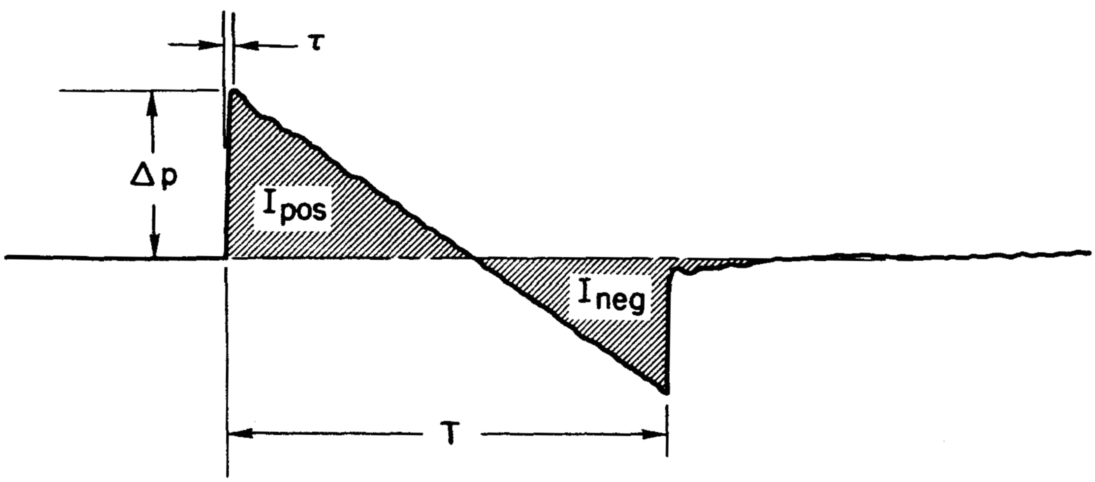

Figure 1.- Tracing of sonic-boom ground-pressure signature.

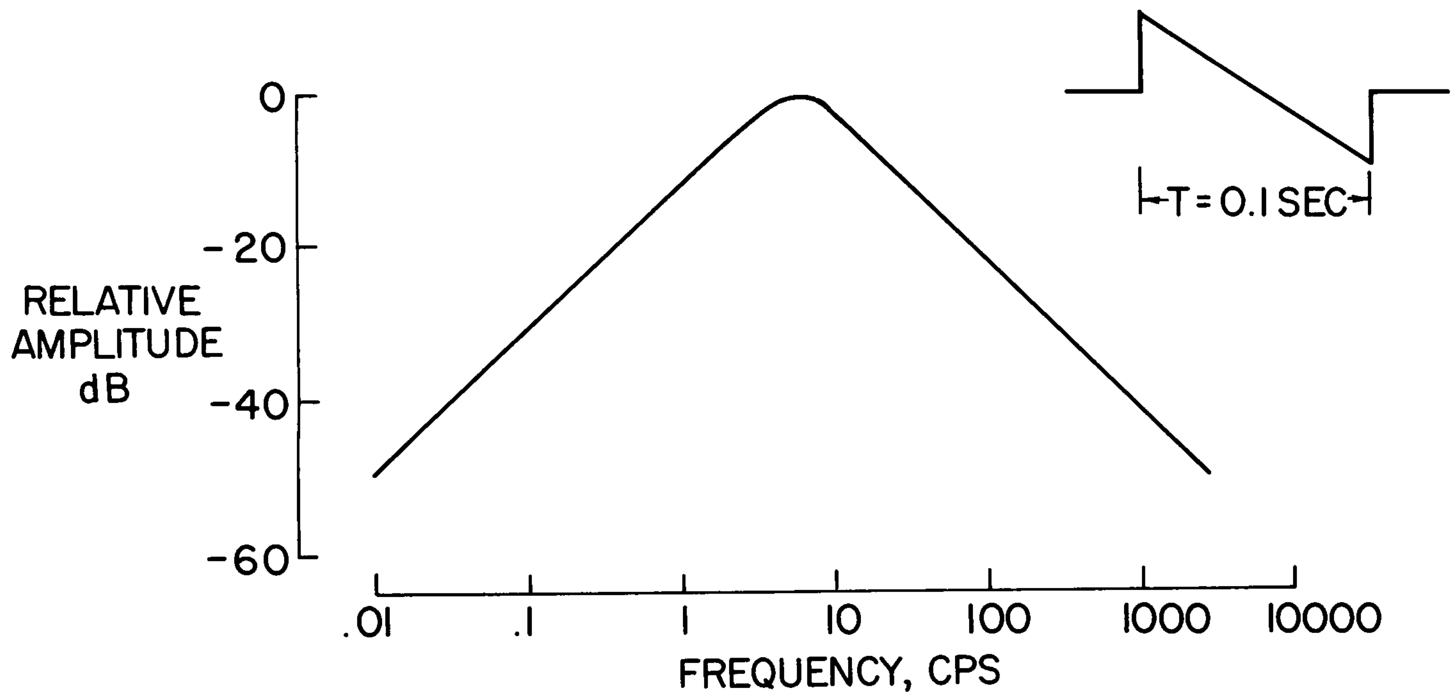

Figure 2.- Spectrum of an N-wave having a period of 0.10 second.

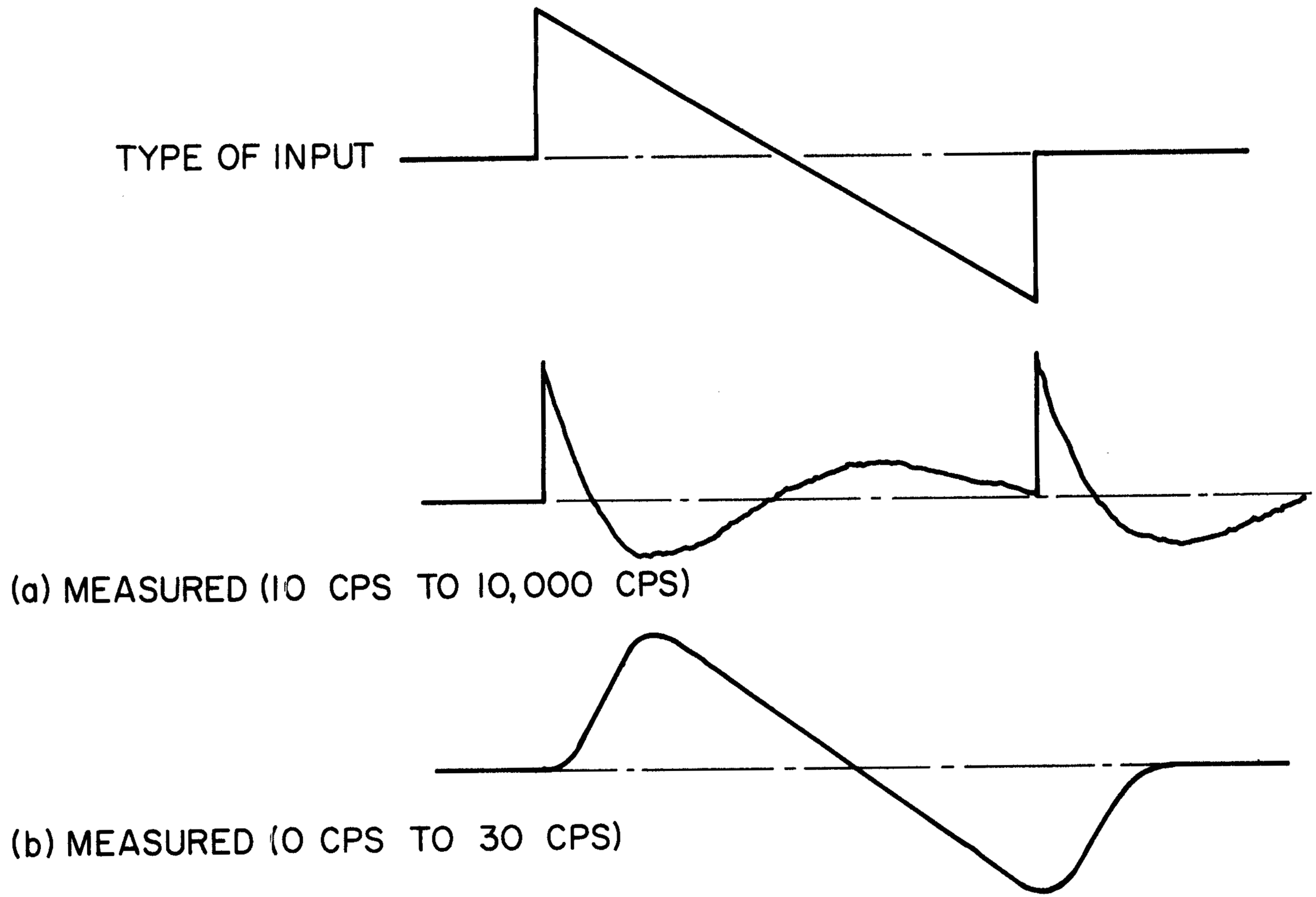

Figure 3.- Effects of overall system frequency response on a sonic-boom pressure signature.

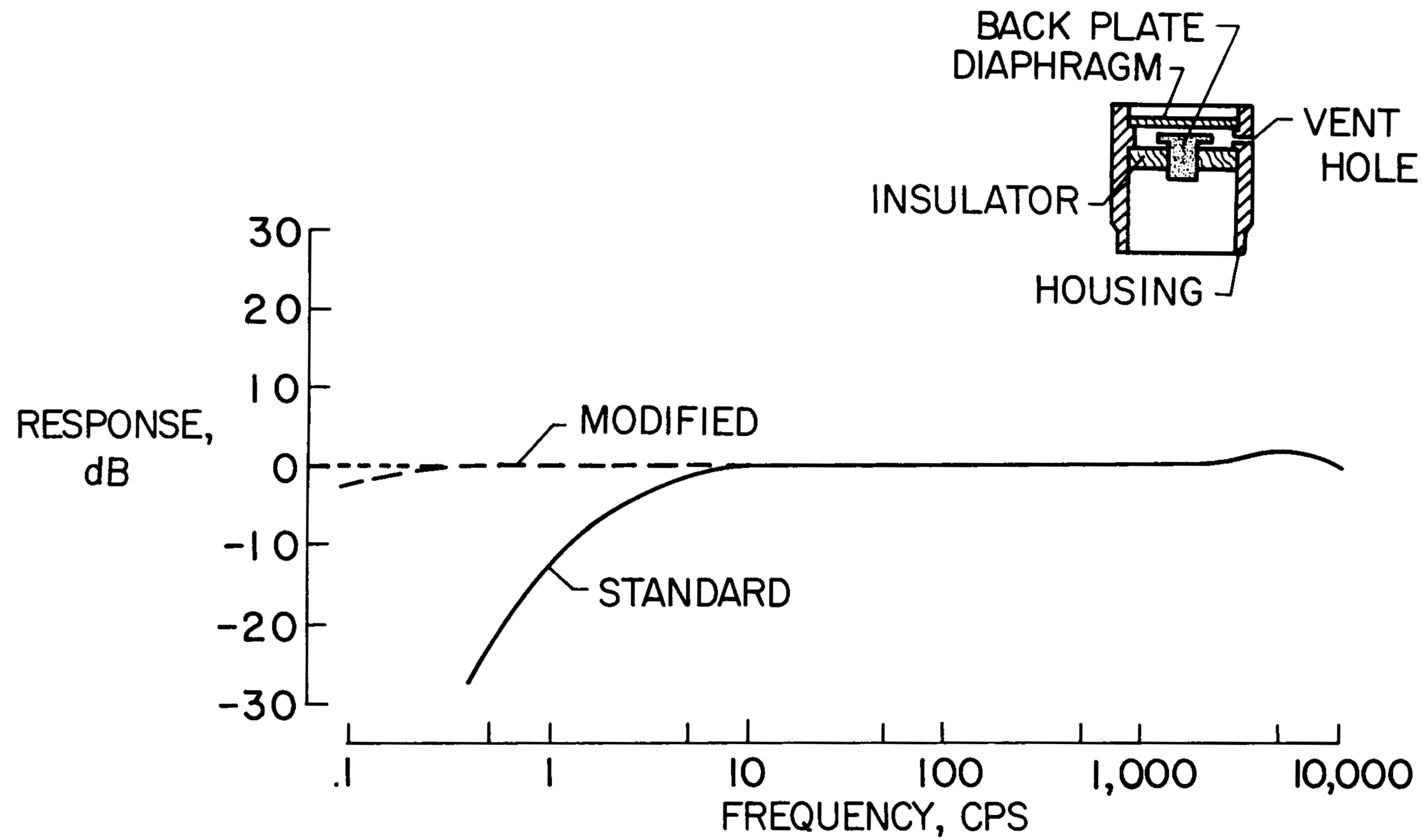

Figure 4.- Frequency responses of a standard and a modified condenser microphone.

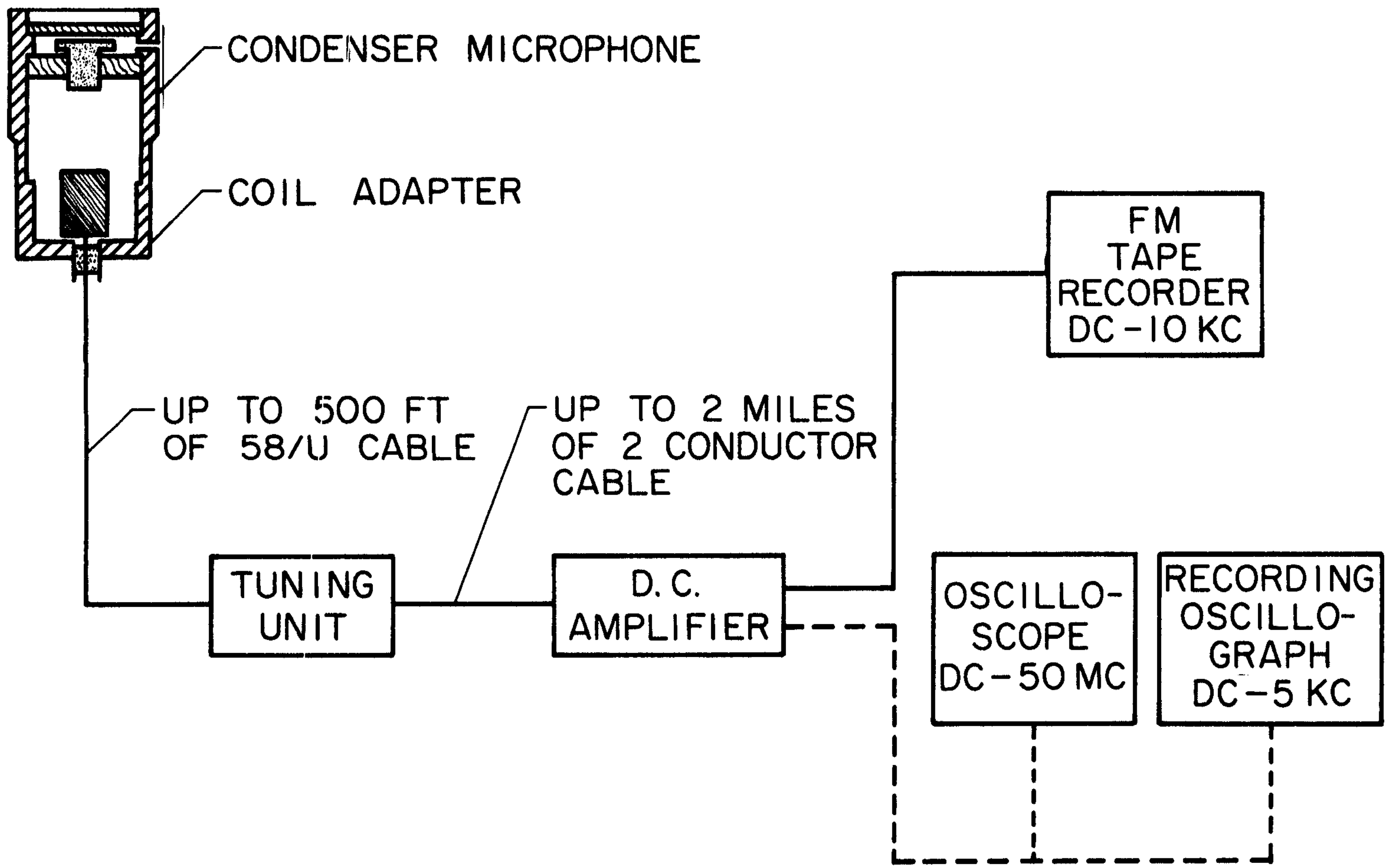

Figure 5.- Block diagram of measuring system.

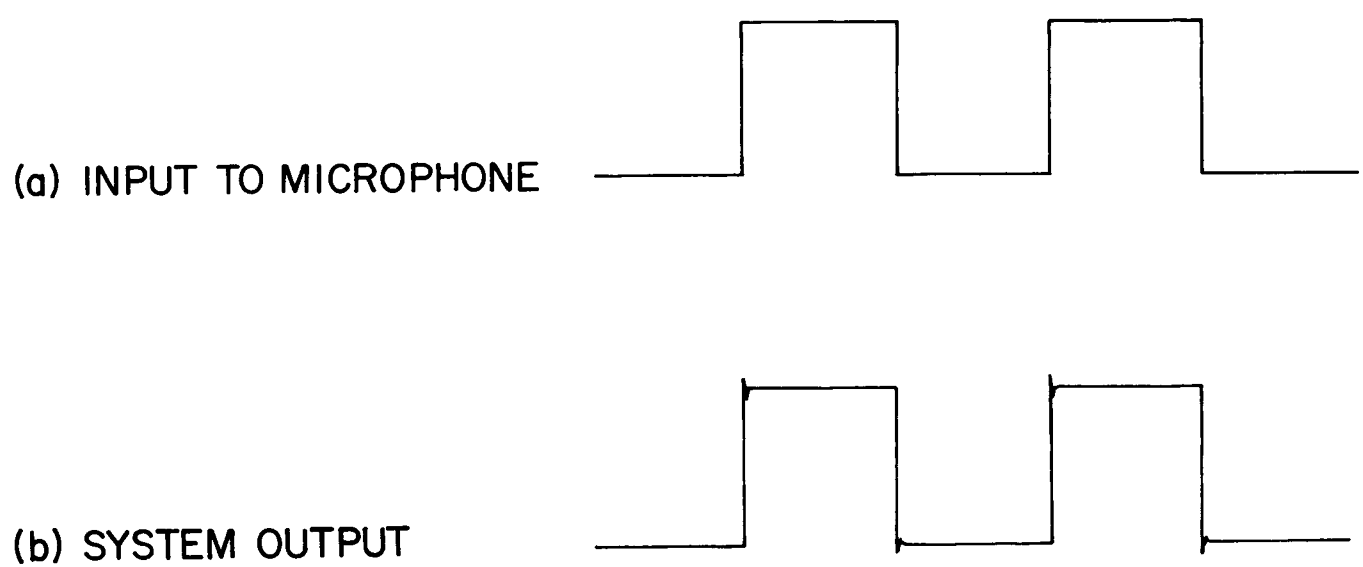

Figure 6.- System-response characteristics of the measuring system for a square-wave-type input having a 20-cps repetition rate and a 50-microsecond rise time.

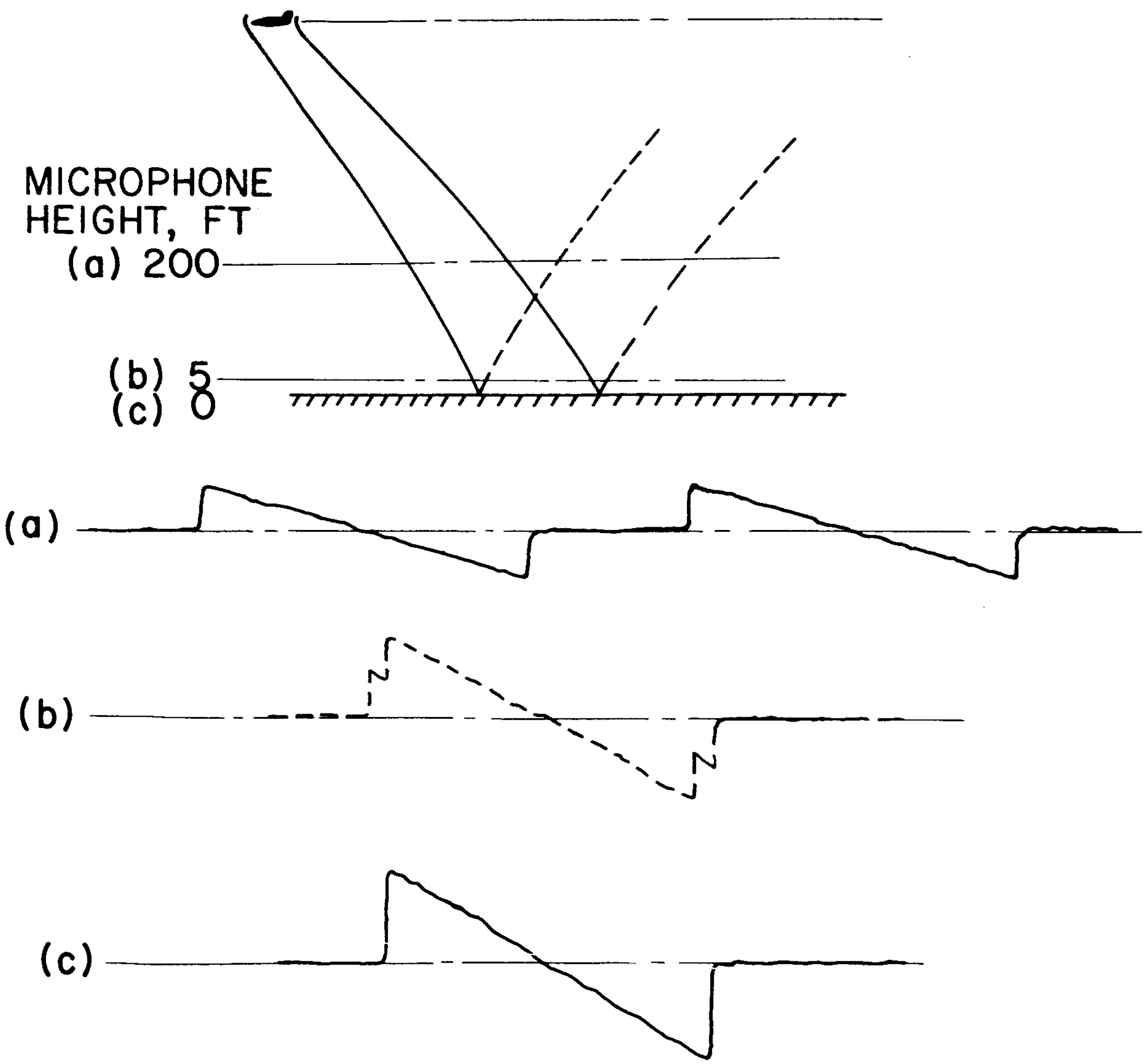

Figure 7.- Effect of microphone elevation on measured sonic-boom signatures.

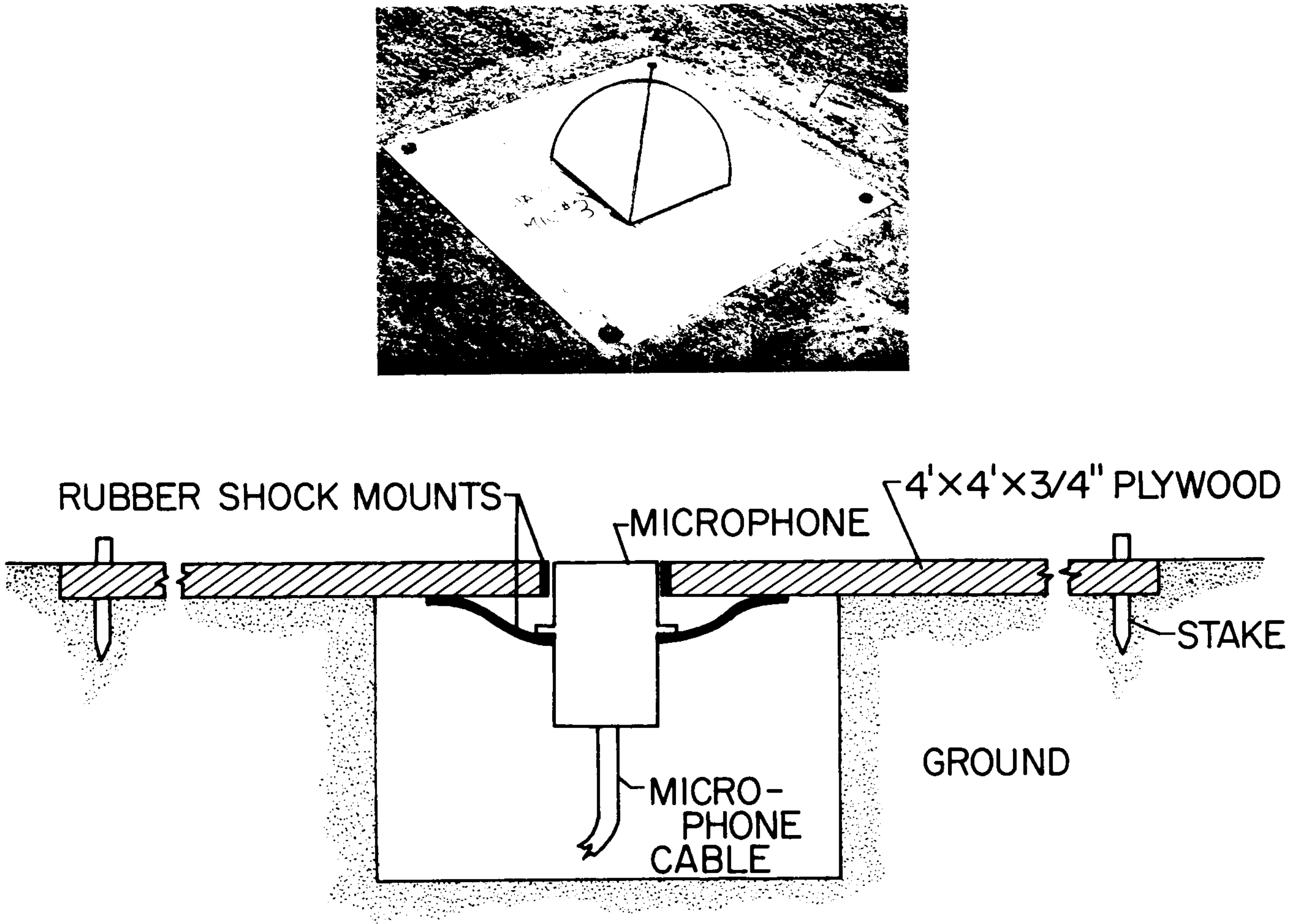

Figure 8.- Ground pressure measurement installation layout.

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